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ASSESSMENT OF SPATIO-TEMPORAL OCCURRENCE OF WATER RESOURCES IN DIDESSA SUB-BASIN, WEST ETHIOPIA

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ABSTRACT

The spatial and temporal occurrence of water resources within watersheds should be properly known for effective resource planning and management. However, direct measurement of parameters describing the physical system is time consuming, costly, tedious, and often has limited applicability; hence, the use of simulation model is becoming attractive. The main objective of the study was to assess the spatial and temporal occurrence of surface water resources in Didessa Sub-basin of the Abbay (Upper Blue Nile) Basin, West Ethiopia. The Soil and Water Assessment Tool (SWAT) was used to model the hydrology of the sub-basin with dataset including soils, land use/cover, digital elevation model, flow and meteorological data [from both conventional meteorological stations and the National Centers for Environmental Prediction’s (NCEP) Climate Forecast System Reanalysis (CFSR) grids]. The study showed that monthly and annual stream flow and hydrologic components in Didessa Sub-basin were predicted by the SWAT hydrologic model with very good values of model performance evaluation parameters. Besides, the study showed that in data scarce areas, the use of satellite data from CFSR grids in conjunction with datasets from few conventional weather monitoring stations can give reliable results of monthly and annual stream flow.

KEYWORDS: SWAT, Hydrologic Modeling, Didessa Sub-Basin, CFSR, Water Resources, Water Yield

INTRODUCTION

Proper planning and management of water resources is vital for wise utilization and sustainable development of the resource. The total renewable surface water resources of Ethiopia are estimated at 122 BCM (billion cubic meters) per year from 12 major river basins, and 22 lakes. Renewable groundwater resources are estimated to be about 2.6 BCM (The World Bank, 2006).

Although there is a universal perception that Ethiopia has adequate water resources, the spatial and temporal occurrence of these resources within a watershed should be properly known for proper planning and management to be effective. The use of simulation modeling, which is concerned with the problem of making inferences about physical systems from measured output variables of the model (e.g, river discharge, sediment concentration), is becoming attractive because direct measurement of parameters describing the physical system is time consuming, costly, tedious, and often has

limited applicability (Abbaspour, Vejdani, & Haghighat, 2007). The problem with obtaining measured data becomes worse when the watershed under consideration is very large; hence the use of simulation models becomes mandatory.

The main objective of the study was to assess the spatial and temporal occurrence of water resources in Didessa Sub-basin of the Abbay Basin, West Ethiopia. The hydrologic components of Didessa Sub-basin were evaluated using the Soil and Water Assessment Tool (SWAT) model. Besides, the hydrologic prediction efficiency of the Climate Forecast System Reanalysis (CFSR) dataset in conjunction with dataset from a few conventional meteorological stations in data scarce areas was also evaluated.

MATERIALS AND METHODS

The Study Area

Didessa Sub-basin forms the southwestern part of Abbay Basin in West Ethiopia. It is situated between 07^{0} 42’40” to 09^{0}58’17” N latitude and 35^{0}33’14” to 37^{0}0752” E longitude (**Figure 1**). The total area of the watershed is about 28,092 square kilometres.

The altitude in Didessa Sub-basin ranges between 609 m.a.s.l at the Didessa-Abbay confluence and 3,211 m.a.s.l at the source of Anger River, one of the major tributaries of Didessa River, in Abe Dongoro District of Horro Guduru Wollega Administrative Zone, Northeast of the Sub-basin. The highlands in the northeastern and southern parts of the sub-basin are higher in altitude than 2100 m.a.s.l. The lowlands, with altitudes less than 1,100 m.a.s.l are located at the eastern remote areas of Anger Sub-watershed and the northern end of the sub-basin, following the valley of Didessa River.

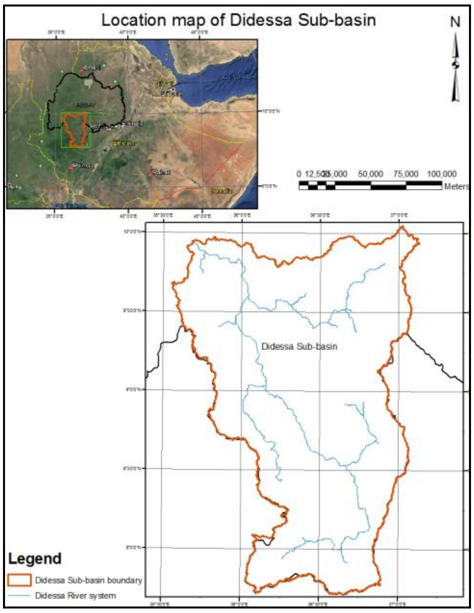

Figure 1: Location Map of Didessa Sub-Basin

Dataset and Data Sources for SWAT Model

The major data types that were used in this study include climate, hydrology, soils, land use/land cover data and Digital Elevation Model. The climate variables required are daily precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity. Table 1 summarizes the dataset used in SWAT modeling of the study area, and their corresponding sources.

Table 1: SWAT Input Data Types and their Corresponding Sources

Data Type	Source	Scale/Period	Description	Remark
Weather	. National Meteorological Agency of Ethiopia . Climate Forecast System Reanalysis' (CFSR) Global Weather Data for SWAT)	1980-2012	Daily precipitation, maximum and minimum temperature, mean wind speed and relative humidity	Many of the station have long period missing.
Hydrology	Ministry of Water, Irrigation and Energy of Ethiopia	1980-2008	Daily and monthly flow data	Many of the station have long period missing.
Land use/cover	Ministry of Water, Irrigation and Energy of Ethiopia	1998	Land use classification map	
Soils	Ministry of Water, Irrigation and Energy	1998	Soil classification map	
Terrain		20 meters	Digital Elevation Model	

Scarcity of weather data is one of the major problems impairing hydrologic modeling and, thereby, proper planning and management of water resources in data scarce watersheds. To minimize the effects of the problem, alternative data source is available. For instance, Dile and Srinivasan (2014) evaluated the performance of SWAT model with weather data from the National Centers for Environmental Prediction's (NCEP) Climate Forecast System Reanalysis (CFSR) (Global Weather, 2014). They concluded that in data-scarce regions such as remote parts of the Upper Blue Nile basin, CFSR weather data could be a valuable option for hydrological predictions where conventional gauges are not available. Similarly, Fuka, *et al*. (2013) presented a method for using the CFSR global meteorological dataset to obtain historical weather data, and demonstrated its application to the modeling of five watersheds representing different hydroclimate regimes. They reported that utilizing the CFSR precipitation and temperature data to force a watershed model provides stream discharge simulations that are as good as or even better than models setup using data from traditional weather gauging stations. Didessa Sub-basin is one of such watersheds with scarce conventional meteorological stations. Hence, in addition to dataset from four conventional meteorological stations, dataset from three data points of CFSR grids have been used (table 2). The climate variables include daily minimum and maximum temperature, precipitation, humidity, sunshine hours and wind speed. Among the four conventional gauging stations, Anger and Bedele have been used as weather generator stations to fill missing data for the conventional meteorological stations.

Table 2: Location Details of the Weather Monitoring Stations

Weather Monitoring Station	Coordinates			Remark
	Latitude	Longitude	Altitude (m. a. s. l)	
Anger	9^{0}27ʹ00”	36^{0}20ʹ00”	1350	Used as weather generator station
Nekemte	9^{0}05ʹ00”	36^{0}27ʹ48”	2080	
Arjo	8^{0}45ʹ00”	36^{0}30ʹ00”	2565	
Bedele	8^{0}27ʹ00”	36^{0}20ʹ00”	2011	Used as weather generator station
P80366	7^{0}57ʹ36”	36^{0}33ʹ47”	1552	CFSR's grid
P95356	9^{0}31ʹ12”	35^{0}37ʹ30”	1559	CFSR's grid
P98369	9^{0}49ʹ48”	36^{0}52ʹ30”	1787	CFSR's grid

Daily and monthly discharge data at different gauging stations in Didessa Sub-basin were obtained from the Ministry of Water, Irrigation and Energy of Ethiopia. Most of the stations have short records and/or many missing data, which hinders the use of these stations for model calibration. Hence, a flow monitoring station called Didessa Near Arjo, with relatively long period of recorded data has been used for model calibration and validation. See table 3 for geographical location of Didessa near Arjo gauging station.

Table 3: Geographical Parameters of Didessa Near Arjo Gauging Station

Flow Monitoring Station	Coordinates		Catchment Area (km^2)
	Latitude	Longitude	
Didessa Near Arjo	$8^0 41^{'} 0$" N	$36^0 25^{'} 0^{"}$ E	9,881.0

Source: Ministry of Water, Irrigation and Energy

Soil parameter data such as soil depth, soil texture, hydraulic conductivity and bulk density, and land use data which are required for the hydrological modeling were obtained from the Ministry of Water, Irrigation and Energy of Ethiopia. Besides, the recent description of land use by Oromia Water Works Design and Supervision Enterprise (unpublished report) was adopted. See, respectively, table 4 and **Figure 2** for detailed distribution and map of the sub-basin's soils.

Table 4: Detailed Distribution of Soil Types in Didessa Sub-Basin

Sr. No.	Soil Name	Area (ha)	Area (%)
1	Dystric Leptosols	15,761.84	56.108
2	Eutric Leptosols	5,336.07	18.995
3	Dystric Cambisols	2 ,088.92	7.436
4	Eutric Regosols	1,767.55	6.292
5	Eutric Vertisols	,447.30	5.152
6	Haplic Alisols	1,205.15	4.290
7	Haplic Acrisols	215.18	0.766
8	Haplic Arenosols	159.84	0.569
9	Rhodic Nitisols	101.13	0.360
10	Haplic Nitisols	8.43	0.030
11	Eutric Fluvisols	0.28	0.001
	Total	**28,092**	**100**

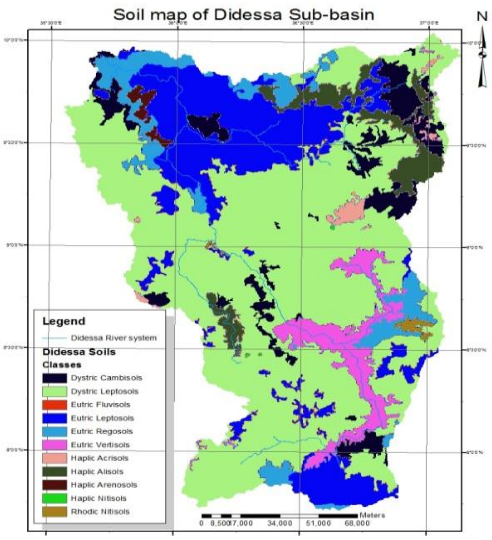

Figure 2: Soil Types in Didessa Sub-Basin

A Digital Elevation Model (DEM) with 20 m resolution was used to derive the primary terrain attributes of slope and specific catchment area. See table 5 for detailed slope distribution and **Figure 3** for elevation map of the study area.

Table 5: Detailed Slope Distribution in the Watershed

Sr. No.	Slope Range (%)	Area (%)	Area (km^2)
1	0-3	2.56	719.15
2	3-6	7.44	2,090.04
3	6-12	20.71	5,817.85
4	12-30	46.78	13,141.42
5	Above 30	22.51	6,323.50
	Total	**100.00**	**28,092**

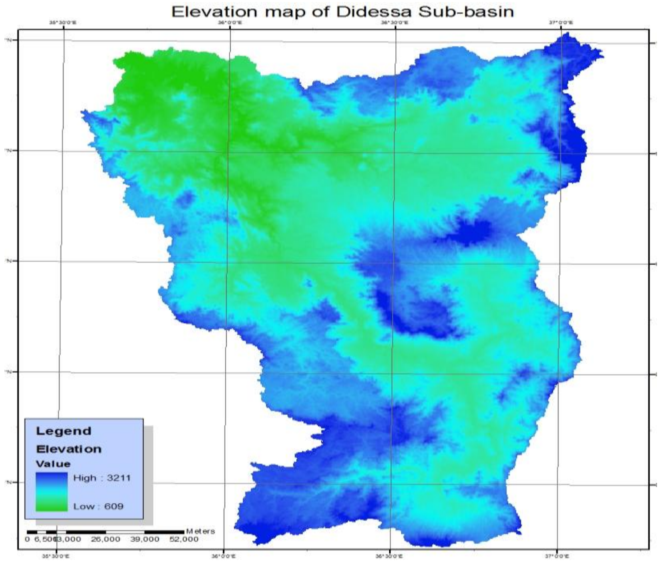

Figure 3: **Elevation Map of Didessa Sub-Basin**

Didessa Sub-basin is predominantly covered with woodlands, followed by agricultural practices. The central and southern parts of the basin are predominantly cultivated (**Figure 4**).

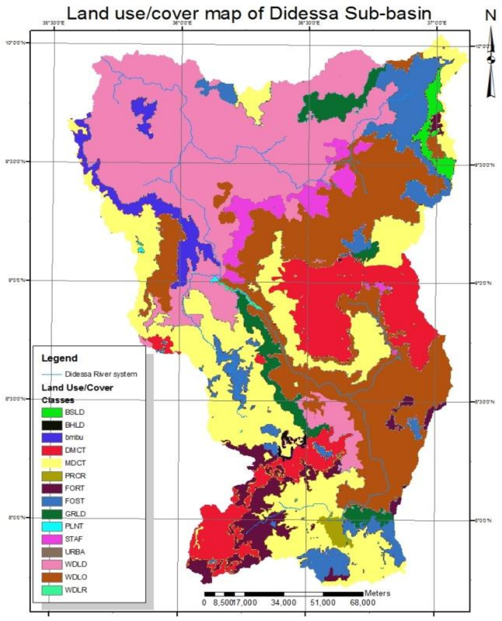

Figure 4: Major Land Use/Cover Distribution in the Watershed

Software and Models Used

ArcSWAT, an ArcGIS extension, which is a graphical user interface for the SWAT (**S**oil and **W**ater **A**ssessment **T**ool), was used to model the hydrology of Didessa Sub-basin. SWAT is a river basin, or watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Winchell, Srinivasan, Luzio, & Arnold, 2009).

SWAT has been employed to model watersheds of different scales for different purposes. For example, Asres and Awulachew (2010) applied SWAT to the Gumara watershed of the Abbay Basin to predict sediment yield and runoff, to establish the spatial distribution of sediment yield and to test the potential of watershed management measures to reduce sediment loading from hotspots. Similarly, Chekol, *et al.* (2007) used SWAT model to assess the spatial distribution of water resources and analyze the impact of different land management practices on hydrologic response and soil erosion in the Upper Awash River Basin watershed, Ethiopia, so as to gather information for effective watershed management. Both groups of investigators reported that they obtained good results.

Likewise, Singh, *et al.* (2013) applied SWAT to the Tungabhadra catchment in India for the measurement of stream flow, and reported that they obtained a result in which the observed and simulated data had excellent correlation during monthly calibration time step. Panhalkar (2014) also used SWAT to estimate the runoff of the Sutluj Basin, India, and reported a successful performance and applicability of SWAT model.

Model sensitivity analysis, the process of determining the rate of change in model output with respect to changes in model inputs (parameters), was initially performed using SWAT model's inbuilt procedures, and the most sensitive model parameters were identified. After the initial setup, the Sequential Uncertainty Fitting version 2 (SUFI-2) algorithm of SWAT Calibration and Uncertainty Programs (SWAT-CUP) was applied to re-identify the most sensitive model parameters and calibrate the model (Abbaspour, 2014). Currently, there is a wide application of SWAT-CUP in calibration and uncertainty analysis of SWAT models. Gebremicael, *et al.* (2013) applied SUFI-2 to calibrate SWAT model of the Upper Blue Nile with the intention of analyzing the trend of runoff and sediment changes, and obtained best fitting model evaluation parameters. Rathjens and Oppelt (2012) applied the SUFI-2 optimization algorithm of SWAT-CUP on a SWAT model of a sub-catchment of the River Elbe (Northern Germany) to identify the most sensitive model parameters.

Singh, *et al* .(2013) applied SUFI-2 technique to evaluate the performance of their SWAT model for the stream flow measurement of the Tungabhadra catchment in India; and they reported that the obtained results showed good harmony between the observed and simulated discharge at the 95% level of confidence (95% prediction uncertainty/95PPU).

SWAT-CUP was setup with the calibration parameters on table 6, and their corresponding maximum and minimum range of values, which was taken from SWAT Users Guide. SWAT-CUP was iterated and the fitted values for the most sensitive parameters affecting the flow were identified.

Table 6: SWAT Calibration Parameters with their Respective Sensitivity Ranking and Fitted Values

Parameter Name	Description and Units	Sensitivity Rank	Range of Values		Fitted Value
			Minimum	Maximum	
CN_2	Initial Soil Conservation Service (SCS) runoff curve number for moisture condition II (-)	1	35	98	55.6
EPCO	Plant evaporation compensation factor (fraction)	12	0	1	0.435
ESCO	Soil evaporation compensation factor (fraction)	10	0	1	0.689
OV_N	Manning's "n" value for overland flow	13	0.01	30	6.758
ALPHA_BF	Base flow alpha factor (decimal)	7	0	1	0.263
REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur (mm)	11	0	500	15.5
GWQMN	Threshold depth of water in the shallow aquifer for return flow to occur (mm)	3	0	5,000	215.0
SHALLST	Initial depth of water in the shallow aquifer (mm)	5	0	1,000	321.0
DEEPST	Initial depth of water in the deep aquifer (mm)	8	0	3,000	945.0
GWHT	Initial groundwater height (m)	9	0	25	24.525
GW_SPYLD	Specific yield of the shallow aquifer (m^3/m^3)	6	0	0.4	0.025
SOL_AWC	Available soil water capacity (mm/mm)	2	0	1	0.999
GW_DELAY	Groundwater delay time (days)	4	0	500	19.5

Model Sensitivity Analysis, Calibration and Validation

Model calibration is the process of estimating model parameters by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions, while model validation involves running a model using input parameters measured or determined during the calibration process (Moriasi, *et al*, 2007). To perform such studies as the evaluation of the impact of alternative land management practices on stream water quality and quantity, first the model must be calibrated and validated for existing conditions (Arnold, et al, 2011). Proper model calibration is important in hydrologic modeling studies to reduce uncertainty in model simulations (Moriasi *et al*, 2007). By citing different sources, Moriasi *et. al.* (2007) suggests processes that should involve in ideal model calibration as: (1) using data that includes wet, average, and dry years, (2) using multiple evaluation techniques (3) calibrating all constituents to be evaluated. The calibration/validation process consists of three steps (Neitsch, Arnold, Kiniry, & Williams, 2011):

- Selecting some portion of observed data
- Running the model at different values for unknown parameters until fit to observations is good
- Applying model with calibrated parameters to remaining observations.

The SWAT model for Didessa Sub-basin hydrology was calibrated for recorded data at Didessa Near Arjo flow monitoring station. As no automatic calibration procedure can substitute for actual physical knowledge of the watershed, which can translate into correct parameter ranges for different parts of the watershed (Arnold, et al, 2012), the calibration procedure involved sensitivity analysis followed by semi-automated calibration procedure by SWAT-CUP, where, at times, manual manipulation on the selection of calibration parameters was necessary.

Didessa Near Arjo station was selected for the mere reason that it has relatively better data availability (long term recorded data), although the amount of missing data is still large.

The station is an outlet for 9,711 km^2 (35%) of the total basin area. The years 1980 and 1981 were used as a warm-up period to enable the model to initialize smoothly (Abbaspour K. C, 2014). Monthly flow data for 1982-1986 and 1992-1996 were used for calibration and validation, respectively. The Nash–Sutcliffe Efficiency (NSE) was used as an objective function to calibrate and validate the model using 13 flow sensitive input parameters included in the model (table 6).

The model was calibrated using the Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT-CUP, an interface that was developed for SWAT (Abbaspour K. C, 2014). SUFI-2 identifies a range for each parameter in such a way that upon propagation: 1) the 95% prediction uncertainty (95PPU) between the 2.5th and 97.5th percentiles contains (brackets) a predefined percentage of the measured data, and 2) the average distance between the 2.5th and 97.5th prediction percentiles is less than the standard deviation of the measured data (Abbaspour K. C, 2005).

Calibration Criteria

After extensive analysis of published literature on watershed modeling, Moriasi *et al*, (2007) has developed general model evaluation guidelines for a monthly time step. Accordingly, they concluded that a general visual agreement between observed and simulated constituent data would indicate adequate calibration and validation over the range of the constituent being simulated. They recommended that visual observation should be followed by calculation of values for three model performance evaluation criteria: Root Mean Square Error (RMSE)-observations standard deviation ratio (RSR), Nash-Sutcliffe Efficiency (NSE), and Percent bias (PBIAS). Moriasi *et al*, (2007) describe the parameters as follows:

RMSE-Observation Standard Deviation Ratio (RSR): RSR is calculated as the ratio of the root mean square error and standard deviation of measured data, as shown in the following equation:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs}-Y^{mean})^2}\right]}$$

where $RMSE$ is root mean square error, $STDEV_{obs}$ is standard deviation of observed data of the constituent being evaluated, Y_i^{obs} is the i^{th} observation for the constituent being evaluated, Y_i^{sim} is the i^{th} simulated value for the constituent being evaluated, Y^{mean} is the mean of observed data for the constituent being evaluated, and n is the total number of observations. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value.

Nash-Sutcliffe Efficiency (NSE): The Nash-Sutcliffe Efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in the following equation:

$$NSE = 1 - \frac{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{mean})^2}\right]}$$

NSE ranges between $-\infty$ and 1.0 (1 inclusive), with NSE =1being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values $\leq$0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

Percent bias ($PBIAS$): Percent bias **($PBIAS$)** measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of $PBIAS$ is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. $PBIAS$ is calculated with the following equation:

$$PBIAS = \frac{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim}) * (100)}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs})}\right]}$$

where $PBIAS$ is the deviation of data being evaluated, expressed as percentage.

With these values, model performance can be judged based on general performance ratings as proposed by Moriasi, *et al*. (2007). Moreover, **Coefficient of Determination(R^2),** the index of correlation of measured and simulated values, has been used to evaluate the accuracy of the overall model calibration and validation. The value of R^2 ranges between 0 and 1. The more the value of R^2 approaches 1, the better is the performance of the model and the values of R^2 less than 0.5 indicates poor performance of the model.

RESULTS AND DISCUSSIONS

Modeling of Didessa Sub-Basin Hydrology and Evaluation of the Model

Watershed Delineation and Model Setup

ArcGIS with ArcSWAT extensions was used to delineate the catchment area of Didessa Sub-basin and its sub-catchments. The Shuttle Radar Topography Mission (SRTM's) Digital Elevation Model (DEM) with 20 meters resolution was used to delineate the watersheds and generate land slope. The outlets (pour points) of the catchments were identified using available maps in hard copy and satellite images. Didessa Sub-basin is the largest of all sub-basins in the Abbay Basin. It drains an area of about 28,092 km^2.

In Didessa Sub-basin SWAT model setup, streams were defined based on a drainage area threshold of 56,000 hectares. The value was chosen from the possible range of values proposed by SWAT. Accordingly, 29 subbasins were created. The model has been setup for the land use/cover, soils and land slope threshold values of 2% for land use, 5% for soils and 10% for land slope, as a result of which 608 homogenous hydrologic response units (HRUs) were created. HRUs are points of a subbasin that possess unique land use/management/soil attributes (Arnold, *et al*, 2011).

Model Calibration and Verification Results

Following the model sensitivity analysis and calibration procedure using SWAT-CUP's SUFI-2 algorithm, the graphical (visual observation) method and values of statistical parameters recommended by Moriasi *et al.* (2007) were considered as adequate statistical values for acceptable calibration. The model was simulated 500 times during both the

calibration and validation periods. **Figure 5** and **Figure 6** are graphical representations of the comparison of observed and simulated flow values for, respectively, the calibration and validation periods at Didessa Near Arjo flow monitoring station.

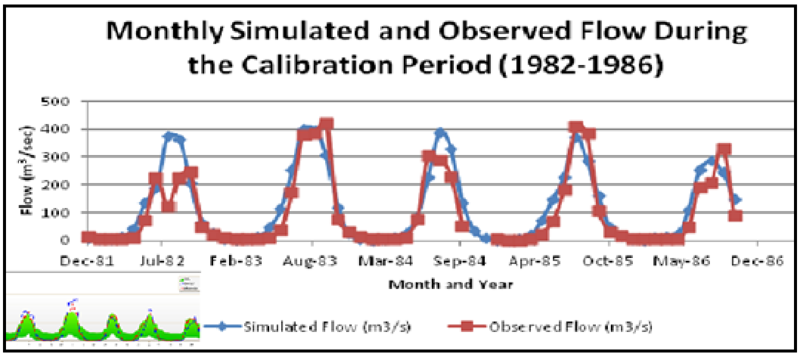

Figure 5: Comparison of Observed and Simulated Monthly Discharge for the Calibration Period (1982-1986)

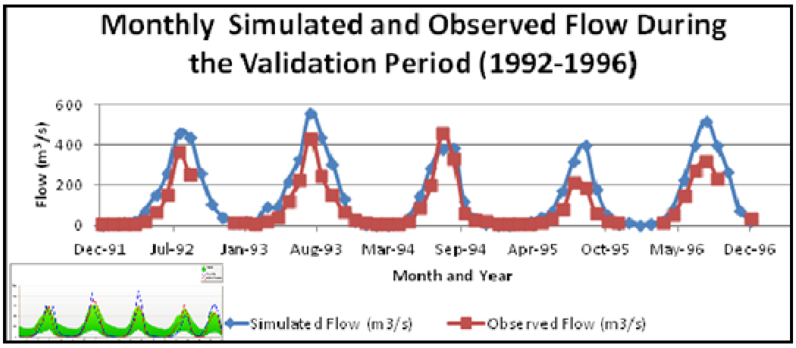

Figure 6: Comparison of Observed and Simulated Monthly Discharge for the Validation Period (1992-1996)

The two figures portray that there is good harmony between observed and simulated monthly flow for both the calibration and verification periods, i.e, the graphs for observed data and the corresponding simulated values show similar patterns. This observation was evidenced using the well known model evaluation parameters, which were used to assess the performance of the model. Among these, the values for Nash-Sutcliffe Efficiency (NSE) and the coefficient of determination (R^2) were above 0.8 for both the calibration and validation periods. RMSE-observation standard deviation ratio (RSR) was 0.36 and 0.45 for the calibration and validation periods, respectively (table 7).

Table 7: SWAT-CUP Simulation Results for the Calibration and Validation Periods

Model Evaluation Parameter	Simulation Results		Remark
	Calibration	Validation	
RSR	0.36	0.45	Very good
NSE	0.87	0.80	Very good
PBIAS (%)	-2.3	10.7	Very good for calibration and good for validation periods.
R^2	0.87	0.80	Very good
P-factor	0.77	0.76	
R-factor	0.94	0.75	

Overall, the model has demonstrated a very good performance.

Water Resources Potential

Mean Annual Water Budget of the Main Stem of Didessa River

The simulated annual water yield of Didessa Sub-basin (at the outlet of the main stem of Didessa River) is **381.37 mm**, while the total annual rainfall is **1,774.20** mm. Conway (2000) reported mean annual runoff depths of 723 mm and 772 mm, respectively, for Didessa and Anger rivers at two distinct measuring stations [Canway (2000) and some other authors consider Didessa and Anger rivers as separate sub-basins of the Abbay Basin, while Anger River is physically a tributary of Didessa River]. The figures seem exaggerated, but Conway (2000) has accounted the very high runoff depths of some stations in his report to the possible measurement errors. On the other hand, Awulachew, *et al.* (2008) reported runoff depths of 289 mm and 298 mm, respectively, for Didessa and Anger rivers, with a total annual runoff volume of 8.028 km^3. Likewise, the mean annual runoff generated from the catchments of Didessa and Anger rivers, as estimated by McCartney, *et al.* (2012) is 346 mm, and the corresponding flow volumes are 6.791 km^3 and 2.733 km^3, respectively. According to McCartney, *et al.* (2012) the total mean annual flow generated from the two catchments with a total catchment area of about 25,500 km^2 was 9.524 km^3. Hence, the results obtained at different times vary; but the values of model evaluation parameters for the present study show that the results are quite trustworthy.

The total water yield is calculated as:

$$Water\ Yield = Surf\,Q + LatQ + GroundwaterQ - Transmission\ Losses, all\ in\ mm.$$

The lion's share (51%) of the water yield is constituted by lateral flow. Lateral flow is water flowing laterally within the soil profile that enters the main channel during the time step. Groundwater contribution to the stream flow, i.e, water from the shallow aquifer that enters the main channel during the time step, holds the second major share. It contributes 34% of the total water yield. The rest of the water yield (16%) comes from surface runoff. About 1% of the flow is lost through transmission, i.e, the average rate of water loss from the reach by transmission through the streambed during the time step. Table 8 and **Figure 7** show the details.

Table 8: Average Monthly Basin Values of the Main Stem of Didessa River

Month	Rainfall (mm)	Surf Q (mm)	Lat Q (mm)	Water yield (mm)	ET (mm)	PET (mm)
January	9.54	0.01	1.05	1.08	19.25	106.55
February	13.88	0	0.88	0.88	18.02	119.69
March	50.72	0.12	2.85	2.96	35.5	119.1
April	80.84	0.65	5.18	5.92	48.09	118.92
May	184.39	3.72	14.55	18.51	62.69	111.61
June	303.23	10.69	30.21	45.06	66.97	89.53
July	358.63	17.21	40.98	74.88	59.06	74.32
August	347.08	15.64	41.5	95.2	63.85	80.42
September	264.41	8.42	32.78	81.67	71.94	94.37
October	113.04	3.59	16.29	41.36	53.83	101.6
November	33.13	0.65	5.67	11.16	30.18	94.54
December	15.7	0.07	2.2	2.71	21.13	103.85
Total (Mean Annual Values)	**1774.20**	**60.77**	**194.14**	**381.39**	**550**	**1211.4**

where Surf Q=surface runoff, Lat Q=lateral flow, Water yield=total water yield, ET=evapotranspiration, PET=potential evapotranspiration.

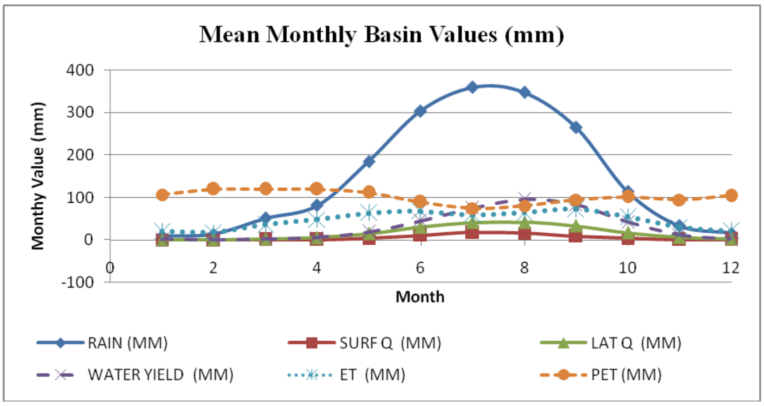

Figure 7: Simulated Average Basin Values for the Main Stem of Didessa River at its Outlet

The average annual groundwater flow and transmission loss are, respectively, 129.55 mm and 3.08 mm.

The results show that the average runoff coefficient in Didessa Sub-basin is **0.21.** The total flow from the sub-basin amounts to about **10.71** BCM per year. This accounts for about 19.54% of the total estimated mean annual flow from the Abbay Basin (54.8 BMC) as measured at the Sudan boarder (Awulachew, *et al*, 2007).

Water Budget of the Major Tributaries

Outputs of the SWAT hydrological model for Didessa Sub-basin on the water yield of the major tributaries has also been evaluated. The four major tributaries of Didessa River are Anger, Dabena, Wama and Upper Didessa.

In terms of size of the catchment area and contribution to the total runoff of Didessa River, Anger Sub-watershed stands first among the tributary watersheds of the sub-basin. The mean annual rainfall in Anger Sub-watershed is about 1,770 mm, and the mean annual runoff is about 428 mm (higher than the figure reported by Awulachew, *et al.* (2008). Hence, the runoff coefficient is 0.24. Anger Sub-watershed contributes an annual total runoff of 3.31 BCM (i.e, about 6% of the total flow of Abbay River as measured at the Sudan boarder) to Didessa and thereby, Abbay.

The other important sub-watershed in Didessa Sub-basin is Dabena Sub-watershed, with a catchment area of 3,341.2 km^2. This watershed receives a mean annual precipitation of 1,886 mm, with the highest evapotranspiration rate of 683 mm per year. The mean annual runoff from the watershed is 366 mm, resulting in a runoff coefficient of 0.19.

Wama is among the top important sub-watersheds in terms of share in Didessa Sub-basin's annual runoff volume. It drains a catchment area of about 3,373.4 km^2. It receives a mean annual rainfall of 1,934.64 mm (the highest among Didessa Sub-watersheds) and the mean annual runoff is about 448 mm. Hence, the average runoff coefficient in the watershed is 0.23.

The mean annual rainfall in Upper Didessa Sub-watershed, the reach of Didessa River upstream of its confluence with Wama River, is about 1,797, and the mean annual runoff is about 358 mm, resulting in a coefficient of runoff of 0.20. It drains an area of 5,539.60 km^2. It is an important sub-watershed where the dam and reservoir for Arjo-Didessa Irrigation Development Project, a project which is intended to develop about 80,000 ha of land through irrigation, is being constructed. The results are summarized on table 9 and **Figure 8**.

Table 9: Mean Annual Water Budget of the Major Tributaries

No.	Name of Tributary/Reach	Precipitation (mm)	Mean Annual Flow (m^3/s)	SURQ	GWQ	PET	ET	Total Annual Water Yield	
								Volume (10^9 m^3)	Depth (mm)
1	Anger	1,769.97	104.90	87.29	133.3	1,169.4	499.2	3.310	427.78
2	Dabena	1,886.12	38.70	37.46	85.2	1,329.5	683.1	1.221	365.53
3	Wama	1,934.64	47.88	69.05	195.9	1,129.8	524.4	1.511	447.90
4	Upper Didessa	1,796.80	62.87	38.52	144.0	1,188.9	571..9	1.984	358.16

The dam for Arjo-Didessa Irrigation Development Project is being constructed at about 1.5 km upstream of the confluence of Wama and Upper Didessa rivers. The dam site drains a catchment area of about 5,536.0 km^2. The mean annual flow at the dam site is about 62.82 m^3/s (total of 1.983 BCM), a sub-watershed average of about 358 mm.

It can be observed that there is variability in water yield between the tributary watersheds and the basin average. This may be due to the differences in catchment behavior (land use/cover, soil types and relief).

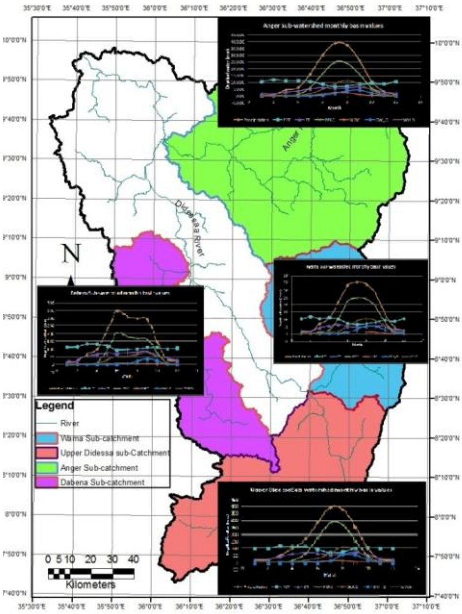

Figure 8: Mean Monthly Values for the Major Sub-Watersheds of Didessa River

SUMMARY

The SWAT hydrologic modeling of Didessa Sub-basin involved setting up the model using a DEM of 20 meters resolution, land use/cover, and soils data of the study area. Weather data from four conventional meteorological stations were used. These stations are concentrating around the middle of the watershed, and hence it was envisaged that the model setup using dataset from the four stations alone may not predict the intended parameters with sufficient accuracy. Hence, additional dataset from three grids of the Climate Forecast System Reanalysis (CFSR) were used, making the distribution of weather monitoring stations fairly uniform across the sub-basin. The model setup was followed by a sensitivity analysis using SWAT's in-built default parameters for flow, and the most sensitive model parameters were identified. The final model calibration and validation were performed using the Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT Calibration and Uncertainty Programs (SWAT-CUP).

The model predicted monthly discharge with high accuracy, with NSE values of 0.87 and 0.80 for the calibration (1982-1986) and validation (1992-1996) periods, respectively; and R^2 values of 0.87 and 0.80 for the calibration and validation periods, respectively. The calibration and validation of the model were performed for a measured flow data at Didessa near Arjo gauging station, which is located at $8^0 41' 0''$ N latitude and $36^0 25' 0''$ E longitude.

The mean annual precipitation in Didessa Sub-basin is about 1,774.20 mm. The mean annual water yield is about 381.4 mm (**10.71** BCM). The water yield is majorly constituted by lateral flow (51%) followed by groundwater flow (34%). The rest (16%) comes from surface runoff, while about 1% of the flow is lost through transmission. Temporally, the months of June to September are the period during which the sub-basin receives most of the precipitation. About 71% of the rainfall comes during this period. Likewise, about 78% of the total water yield occurs during this period. The period is, of course, the main rainy season in the area. The months of November to February are the period during which the area receives the minimum amount of rainfall (about 4%). About 4.15% of the annual water yield of the sub-basin is generated during this period.

Spatially, there is variability in both the amount of precipitation the area receives and the runoff generated, between the sub-basin average and that of the major tributaries. Draining the widest area of all the major tributaries, Anger Sub-watershed receives a mean annual rainfall of about 1,770 mm, and generates a mean annual water yield of about 428 mm (3.31 BCM). Wama Sub-watershed receives the highest annual rainfall (about 1,935 mm) followed by Dabena (1,886 mm) and Upper Didessa Sub-watershed (1,797 mm). Wama Sub-watershed generates the highest rate of runoff (about 448 mm) followed by Anger Sub-watershed (428 mm) and Upper Didessa Sub-watershed (358 mm). The amount of water yield is not proportional to the amount of rainfall received, as this should be a function of the watershed characteristics (land use/cover, soils, and land slope).

CONCLUSIONS

The monthly and annual stream flow of the main stem of Didessa River and its major tributaries has been predicted by a SWAT hydrologic model, a model which performed very well. Besides, the monthly and annual precipitation and evapotranspiration have been predicted. Although the values of the parameters which have been predicted by SWAT in this study are somewhat different from those reported by previous investigators, the values of the statistical parameters which are often employed to test the predicting efficiency of SWAT model clearly portray that the results of the present study are quite trustworthy.

The study also showed that in data scarce areas, the use of satellite data from Climate Forecast System Reanalysis (CFSR) grids in conjunction with datasets from a few conventional weather monitoring stations can give reliable results of monthly and annual stream flow and other weather parameters. Thus, even though dataset from conventional meteorological stations are still more desirable for greater accuracy and reliability, data scarcity may no longer hinder watershed hydrologic modeling exercises in such areas as Didessa Sub-basin.

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